(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 December 2001 (06.12.2001)

PCT

(10) International Publication Number
WO 01/92002 A2

(51) International Patent Classification[7]: B32B 5/00

(21) International Application Number: PCT/US01/17983

(22) International Filing Date: 1 June 2001 (01.06.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/209,435 2 June 2000 (02.06.2000) US
60/213,509 22 June 2000 (22.06.2000) US

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to the identity of the inventor (Rule 4.17(i)) for all designations*
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for all designations*

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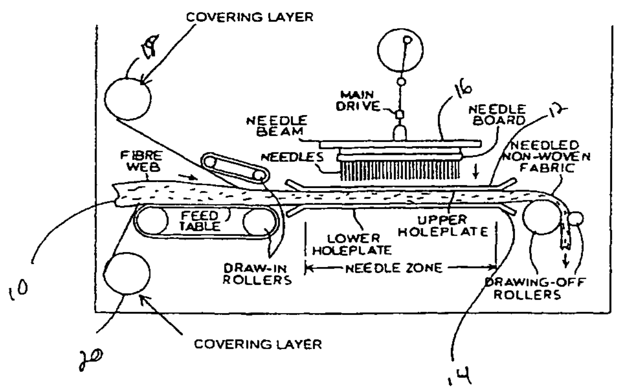
(54) Title: METHOD FOR CONSOLIDATION FOR RANDOM CARBON FIBER ORIENTATION AND FOR FORMING A CARBON FIBER PREFORM



(57) Abstract: The present invention is a method of forming a composite including a carbon fiber layer surrounded by at least a single layer of non-woven fibers both above and below the carbon fiber layer. The layer(s) of carbon fiber and the layers of non-woven fibers are consolidated with a unique needle-punching method. According to another aspect of the invention, the layer(s) of carbon fiber and the layers of non-woven fibers are consolidated with a stitching method. The present invention also provides a method of forming a preform part, comprising a number of steps. First, arrangement of carbon fibers is coated with a binder, which is either a liquid or dry adhesive. Next, the carbon fiber arrangement is placed on a forming surface. The forming surface can be either a curved or generally flat surface. Third, pressure is applied to the carbon fiber arrangement. A vacuum bag or portions of a conventional mold can be used to apply pressure to the arrangement. Lastly, heat is applied to the carbon fiber arrangement to set the binder. Heat can be applied in a number of ways, including applying an electric current to the carbon fibers to resistively heat the carbon fiber arrangement. Once a sufficient quantity of heat has been applied to set the binder, the resulting preform part is allowed to cool and then removed from the forming surface. The preform part is then ready to be injected with resin and used with a mold to form a finished part.

WO 01/92002 A2

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*
— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *without international search report and to be republished upon receipt of that report*

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METHOD FOR CONSOLIDATION FOR RANDOM CARBON FIBER ORIENTATION AND FOR FORMING A CARBON FIBER PREFORM

DESCRIPTION

Technical Field

The present invention relates to a method for consolidating a layer of carbon fibers with carrying or covering layers of non-woven fibers.

The present invention also relates to a method for producing a carbon fiber preform part that is used to form a finished part; and more particularly, this invention relates to a novel method for applying pressure and heat to a random arrangement of carbon fibers consolidated with a binder to produce a preform part.

Related Cases

The present invention claims priority from United States Provisional Application Nos. 60/209,435 and 60/213,509.

Background of the Invention

The use of carbon fiber in the engineered composite industry has grown over the last 25 years. Generally, carbon fibers are made from either acrylic-based woven precursors, or petroleum by products. Acrylic-based fibers are referred to as pan, and petroleum-based fibers are referred to as pitch. Finished products made from pitch tend to cost more because it takes more equipment and time to produce the finished product. In contrast, the raw material costs for pitch are less than the raw material costs for pan.

Pan and pitch carbon fibers were first used by the aerospace industry for high strength, lightweight application where fiberglass and similar reinforcement were insufficient. However, the price for both types of carbon

fiber was high since only limited quantities were produced. More recently, the use of carbon fibers has expanded into the engineered composite industry, for example golf club shafts, tennis rackets, bicycles, motorcycles, marine and certain automotive applications. Traditionally, carbon fiber is produced in continuous filament bundles that can then be milled and chopped into short-length fibers. The continuous filament bundles and short-length fibers are then packaged for shipment to fabricators. The fabricators, which include those who weave, stitchbond, braid, knit and needlepunch, manufacture the product into the roll good forms identified above for shipment to finished part manufacturers. The product follows the traditional manufacturing steps from raw material to work in progress to finish goods.

Previously, carbon fibers have been produced as random carbon filaments with a diameter of about 10 microns in either a lofty batt or mat configuration. In either configuration, the rough product is characterized by a random arrangement of carbon filaments, with lengths of approximately three inches to twenty four inches, oriented predominantly in the machine or longitudinal direction. The product is mechanically unstable and difficult to handle in this form and requires some type of post-production treatment.

A chemical ("wet – hydro-entanglement") or physical ("air lay") consolidation method has been used historically to effectively entangle the fibers and, with the addition of a chemical binding agent, stabilize the carbon fibers. Both processes form a dense, compressed mat with structural properties orientated predominantly in the "x" axis (or longitudinal direction), limited structure in the "y" axis and negligible structure in the "z" axis (through the thickness). With either process, the thermal, electrical, and mechanical properties of the carbon fiber, are affected due to the dependence on fiber orientation in the "x", "y", and "z" axes. Consequently, these properties are not optimized by either of the consolidation methods. When other traditional methods, such as needle-punching or "felting" are used to consolidate layers of carbon fiber, the actual carbon fiber filaments can be severely damaged with

fiber orientation and mechanical properties compromised. Accordingly, there is a definite need for a consolidation method that preserves and enhances the carbon fiber properties.

A new carbonization process produces an arrangement of carbon fiber with boundaries roughly defining a sheet, which is referred to as batt. Batt is relatively inexpensive to produce and is characterized by a random arrangement of carbon fiber filaments in the machine or longitudinal direction. This means that filaments are positioned longitudinally but randomly arrayed throughout the sheet. As a result of the random arrangement in the machine direction, batt is a high-loft product, meaning that the interstice or space between the intersection of the filaments is measurable. Each carbon filament has a fiber length greater than 3.0 inches and a diameter in the 8.0-15.0 micron range. Typically, carbon fiber batt has a low mass and is structurally unstable. As a result, the commercial utility of batt has been limited to applications where fiber orientation and stability is not critical, such as insulation.

In addition to structural instability, batt suffers from poor handling characteristics. Previous attempts have been made to increase the structural stability of batt and facilitate handling of the product. For example, a backing structure can be chemically adhered to the batt, or a disposable carrier sheet can be secured to the batt. These additions have failed to increase the structural stability of the batt because neither the backing structure nor the carrier sheet provides uniformity in the carbon fiber orientation and density. When other traditional methods, such as stitch-bonding or needle-punching, are applied to batt, the actual carbon fiber filaments are severely damaged and both physical and mechanical properties can be adversely affected.

Because of the low manufacturing cost of batt and its advantageous fiber properties (*i.e.* fiber length and diameter), there is a definite need to use batt carbon fiber products in other applications, including in traditional molding processes to produce a finished part.

Summary of the Invention

In one embodiment of the invention, a method of forming a composite including a carbon fiber layer surrounded by at least a single layer of non-woven fibers both above and below the carbon fiber layer is disclosed. According to one aspect of the invention, the layer(s) of carbon fiber and the layers of non-woven fibers are consolidated with a unique needle-punching method. According to another aspect of the invention, the layer(s) of carbon fiber and the layers of non-woven fibers are consolidated with a stitching method.

The present invention also relates to a method for producing a carbon fiber preform part with increased structural stability that can be used to form a finished part. The increase in structural stability is achieved by use of a chemical or thermoplastic binder applied to, or in intimate contact with, the carbon fiber.

According to one aspect of the invention, pressure is applied to a random arrangement of carbon fibers consolidated with a binder. A high solubility binder comprising a polyester based polyurethane dispersion, such as available from Bayer AG can be used. Typical binder compositions may also include coupling agents, lubricants, emulsifiers and conductivity increasing additives that are dissolved or dispersed in water or a solvent. Thermally activated binders may also be used comprising one or more cross-linkable, film forming polymers which when crosslinked or cured, become insoluble. When set, the binder stabilizes the carbon fibers in the arrangement but allows the arrangement to remain pliable. Heat is then applied to the arrangement to set the binder and form a preform part. In addition to improving the structural stability of the preform part, the disclosed method improves the electrical continuity and conductivity of the preform part without damaging the internal carbon fibers.

According to another aspect of the invention, pressure is applied to a composite structure formed from the combination of a layer or randomly

arranged carbon fibers and layers of pre-consolidated materials combined with a binder. Heat is then applied to the composite structure to set the binder and form a preform part.

According to another aspect of the invention, pressure is applied to a composite structure formed from the combination of a layer of randomly arranged carbon fibers and layers of pre-consolidated materials. A binder is then infused into the composite structure and heat is applied to set the binder and form a preform part. This suspension impregnation process utilizes vacuum to infuse the binder and further employs the vacuum to remove byproducts of the binder processing (i.e. water vapor, volatiles).

According to another aspect of the invention, a low melting temperature binder yarn or filament may be used in the preforming process. These filaments are typically spun from polymers such as nylon, polypropylene, polyethylene or polyester. These low melt polymer filaments can be combined or interlaced with the carbon fibers using conventional methods such as hydroentanglement or textile carding. These processes are performed at a temperature below the melting point of the binder filaments.

Further aspects of the invention are disclosed in the detailed description of the preferred embodiment, the drawings and the claims.

Brief Description of the Drawings

Embodiments of the invention will be described with the aid of the following diagrammatic drawings.

FIG. 1 is a schematic view of needle punch used for consolidating carbon fibers and non-woven fibers according to an aspect of the invention;

FIG. 2 is a partial cross-sectional view of a needle punch board for consolidating carbon and non-woven fibers according to an aspect of the invention;

FIG. 3 is an enlarged cross-sectional view of a portion of the needle punch board in FIG. 2 penetrating the carbon and non-woven fibers;

FIG. 4 is a plan view of randomly arranged carbon fiber filaments in the machine direction;

Figure 5 is a plan view of a first layer of randomly arranged carbon fiber filaments and a second layer of randomly arranged carbon fiber filaments positioned approximately 90 degrees to the first layer; and,

Figure 6 is a side view of a composite structure, including a layer of randomly arranged carbon fibers and a layer of pre-consolidated materials above and below the randomly arranged layer.

Detailed Description of the Preferred Embodiment

While this invention is susceptible of embodiments in many different forms, there is shown in the drawings and will herein be described in detail preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiments illustrated.

Consolidation For Random Carbon Fiber Orientation:

One aspect of the invention concerns a novel method for forming a hybrid composite including a carbon fiber layer or plurality of carbon fiber layers surrounded by at least a single carrying, or covering layer of fibers both above and below the carbon fiber layer(s). As a result of the hybridization, the composite has improved structural properties, over the original batt or mat configuration, in the x, y and z – axes. In addition, the electrical properties of the carbon fibers are preserved, and in some cases, improved.

The carrying of covering layer(s) can be non-woven fibers, such as, for example, polyester, polypropylene, polyethylene, nylon, or aramid staple fibers. By introducing layers of non-woven fibers above and below the carbon fiber layer (also referred to as the carbon mat), the fibers in the carbon mat are protected. The arrangement of the non-woven fibers above and below the

carbon mat carries and covers the carbon mat and protects and stabilizes the carbon mat during subsequent processing.

In a preferred embodiment, the carbon mat and the non-woven fibers are consolidated with a needle-punch technique. The non-woven material can be in a staple fiber configuration that can either be carded, lap and batt condensed on the needle line or manufactured off-line and staged for the needle-punch hybridization. The needles utilized are of a particular design in that they capture fibers from the carrying layers during the down stroke only. The needles contain very small, non-aggressive barbs such that the barb is filled with the carrying layer staple fibers and merely displaces the carbon filaments during the penetration. As the needles are retracted, the staple fibers are partially pulled back through the material and ultimately released thus creating a "z" axis fiber orientation through the composite material thickness.

Referring to FIG. 1, a carbon fiber web 10 is fed between a first or upper plate 12 and a second or lower plate 14, both of which are below a needle board 16. This area is referred to as the needle zone. In addition to the carbon fiber 10, a first or top covering or carrying layer 18, and a second or lower covering or carrying layer 20 of non-woven fibers (as described above), are fed to the needle zone above and below the carbon fiber 10.

The needle board 16 includes a plurality of needles 22 shown in greater detail in FIGS. 2 and 3. The needles 22 include very small barbs 24, that fill with material from the top covering layer 18 as the needles 22 are moved downward through the covering and carbon fiber layers 18, 10, 20. This places fibers from the top covering layer 18 in the z-axis direction of the fabric and consolidates the layers.

Preferably, the covering or carrying layers should have an areal weight in the 3 to 5 oz. square yard weight range. Preferably, the down stroke needle should be a type such as the Foster Needle 36HDB . Also, the frequency of needle penetrations should be between 450 and 1000 penetrations per square inch to provide the desired consolidation, density and thickness. The result is a

composite material that maintains the electrical properties of the carbon fibers and provides structural reinforcement in the x and z-axes. This type of needle-punch operation would be the preferred embodiment if structural and conductive performance characteristics are desired.

Certain composite applications may require anisotropic properties where mechanical strength is required in the y-axis, or cross-machine direction. Typically, the carbon fiber reinforced hybrid described above exhibits high mechanical strength in the machine direction with relatively low tensile properties in the cross-machine direction. In an instance where y-axis structural characteristics are required, high strength, unidirectional products such as glass, carbon, or Kevlar , can be positioned at a 90° angle, relative to the longitudinal direction, immediately above and below the carbon mat. These products will also be consolidated and stabilized in the composite matrix by needling the covering and carrying layers as indicated previously. If a composite fiber architecture with high torsional stiffness is required, additional layers placed at a bias angle relative to the longitudinal directional can be added to the appropriate layers of 90° product. Similarly, various combinations of layers orientated at 0°, 90°, +45°, -45° can be incorporated by tacking or needle-punching to achieve the required mechanical and electrical properties.

Tacking is yet another-form of needle-punching wherein the number of needles used is greatly reduced resulting in a mechanically stable product. This product can then be handled without risk of displacing or disturbing the fiber orientation and incorporated into other hybrid products that will undergo the complete, needle-punch consolidation procedure.

In another preferred embodiment, the carbon mat and the non-woven fibers are consolidated with a stitching technique. With this technique, a plurality of smooth needles, threaded with a fiber or filament passes through the materials drawing a continuous filament through the thickness, effectively "sewing" the layers together. This method can incorporate various materials in the stitching "threads" depending on the desired properties. Again, this method affords little

or no damage to the carbon filaments and can be varied to provide a wide range of stitch penetrations and tensions to accommodate density and thickness. Structure can be added to the z-axis with this method by utilizing high strength stitching fibers and by varying the density and occurrence of the stitching fibers.

In another preferred embodiment, the carbon mat is employed as a high strength core material in a sandwich laminate. By adding high tensile strength materials to the carrying layers, both top and bottom, and maintaining a specific amount of loft and density in the carbon mat, a highly structural, lightweight product can be produced using both the needling and stitching methods.

In another preferred embodiment, the covering and carrying layers are laid together with woven, non-woven, knit, or braided fiber architectures by hand to create an optimum carbon mat hybrid. Subsequently, a soluble binder or adhesive can be applied to the various components and vacuum pressure applied to consolidate. The binder used on the fibers and fabrics should be compatible with any resin matrix selected for use with the composite in the ultimate, finished part. The binders used could also be infused while under vacuum. If a heat activated binder is used, the carbon mat can be resistively heated to assist in the formation of the consolidated product (or *preform*). A resultant effect of this method is an improvement in electrical properties by virtue of the intimate contact formed between the random carbon filaments. The fluid pressure on the carbon mat not only improves electrical conductivity but also improves mechanical performance characteristics by increasing the volumetric ratio of high strength carbon fibers.

Carbon Fiber Preform:

The present invention also relates to a method for using batt, an arrangement of carbon fibers, to produce a preform part that is used to form a finished part. More specifically, this invention relates to a novel method for applying pressure and heat to a random arrangement of carbon fibers consolidated with a binder to form a preform part. In addition to increasing the structural stability of the preform part, the disclosed method ensures electrical continuity

and improved electrical conductivity in the preform part.

A preform part is an intermediate structure or object used in a subsequent process to form a finished part. Commonly, a preform part is used to form a reinforced plastic part. Preferably, the preform part has a structure that is very similar to the finished part. This structural attribute is referred to as a near-net shape. The preforming process partially rigidifies the structure while leaving interstices between the fibers unfilled therefor permitting the use of a matrix resin to subsequently form a molded article.

Batt is an arrangement of carbon fibers, where the boundaries of the fibers roughly define a sheet-like shape. A carbon fiber batt is characterized by a random arrangement of carbon fiber filaments in the machine or longitudinal direction as shown in FIG. 4. This means that filaments are positioned longitudinally but randomly arrayed throughout the sheet. As a result of the random arrangement in the machine direction, a carbon fiber batt is a high-loft product, meaning that the interstice or space between the intersection of the filaments is measurable.

Batt can be formed from either a single layer or multiple layers of randomly arranged carbon fiber filaments in the machine direction. When multiple layers are required, the subsequent layers can be applied over the first layer by the process equipment. The subsequent layers can be positioned in line with the first layer or at various angles to the first layer, such as ± 45 or ± 90 degrees.

In a preferred embodiment, a method of forming a preform part comprises a number of steps. The arrangement of carbon fibers is coated with a binder. When set, the binder stabilizes the carbon fibers in the arrangement. In contrast to resins, binders allow the arrangement to remain pliable. The binder can be in either in a liquid or dry form. The binder must be chemically compatible with any resin that is used in the formation of the finished part. The binder can be applied to the carbon fibers in a number of ways, including but not limited to spraying the binder onto the carbon fibers or submersing the arrangement in a vessel containing

binder. To ensure that the binder stabilizes the carbon fibers, a sufficient quantity must be applied. For example, acceptable dry weight percentages range from 45% fiber and 55% binder to 98% fiber and 2% binder. Preferably, the binder is heat activated or set; however, binders that set at ambient temperatures are compatible with the methods disclosed herein. A suitable binder is Altac® 363E, a dry powder binder that is manufactured by Reichhold Corporation. Other suitable binders are Altac® 363EF, Pretx 100, Pretex 110, Pretex 120, Petex, 130, and Pretex 140, all of which are available from Reichhold Corporation.

The carbon fiber arrangement is placed on a forming surface. Depending upon the shape of the preform part, the forming surface can be either a curved or planar surface. The forming surface can be integrated into a conventional mold or remain a distinct structure.

Pressure is applied to the carbon fiber arrangement to shape or form the arrangement into a desired preform shape. The desired preform shape is a near-net shape, or similar to the finished part shape. The application of pressure improves the structural performance characteristics of the preform part. Pressure can be applied in a number of ways, including but not limited to using a vacuum bag in connection with the forming surface. A vacuum bag is a plastic membrane that is placed over the arrangement and the forming surface to define a cavity. A vacuum is drawn in the cavity thereby exerting pressure on the objects beneath the membrane. Alternatively, the forming surface could be integrated into a lower portion of a mold. A top portion of the mold can be positioned in close proximity to the lower portion such that the top portion exerts pressure on the carbon fiber arrangement to form the arrangement into the preform shape.

Heat is then applied to the carbon fiber arrangement to set the binder. While heat is applied, the carbon fiber arrangement remains in the desired preform shape. Once the binder has set, the carbon fiber arrangement has solidified and become stable; however, the arrangement is still pliable. Unlike a cured resin, a set binder permits the arrangement to remain pliable. As a result of the

solidification, the resulting preform part is no longer structurally unstable and difficult to handle.

Heat can be applied in a number of ways, including but not limited to applying an electric current to the carbon fibers to resistively heat the carbon fiber arrangement. Alternatively, an electric current could be applied to a layer of conductive fibers in the forming surface to resistively heat the forming surface. By applying an electric current to the carbon fiber arrangement and to a layer of conductive fibers in the forming surface, the arrangement and the forming surface could be resistively heated. In yet another manner of heating the carbon fiber arrangement, an electric current could be applied to a layer of conductive fibers in the upper and lower mold portions to resistively heat the forming surface. In addition to applying an electric current to the upper and lower mold portions, an electric current could be applied directly to the carbon fiber arrangement. Alternatively, other conventional methods could be used to heat the carbon fiber arrangement, including ovens, autoclaves, ultraviolet light, or ambient temperatures.

Once a sufficient quantity of heat has been applied to set the binder, the resulting preform part is allowed to cool and is then removed from the forming surface. The preform part is then ready to be used in forming a finished part. For example, the preform part can be infused or injected with curable resin and then subjected to a molding process where the resin is cured to produce a finished part.

In another preferred embodiment, a single layer or multiple layers of randomly arranged carbon fibers or batt are stacked with a single layer or multiple layers of pre-consolidated materials to form a composite structure. Preferably, a single layer of randomly arranged carbon fibers is surrounded by a layer of pre-consolidated material both above and below the randomly arranged carbon fiber layer as shown in Figure 6. The boundaries of the arrangement layer are roughly defined by random arrangement and structure of the carbon fibers. As a result of this arrangement, the composite structure has structural components in the x-axis, the y-axis, and the z-axis. By consolidating layers of pre-consolidated material

above and below the carbon fiber arrangement, the internal carbon fibers are protected. In addition, the electrical conductivity of the carbon fibers in the composite structure remains unaffected by the arrangement.

The pre-consolidated layers result from the combination of either woven or non-woven material layers. Unlike the carbon fiber arrangement layer, the material layers can be combined in a number of conventional mechanical ways, including needling, stitch-bonding, knitting, and braiding. The arrangement of the pre-consolidated layers above and below, "carries" and "covers" the carbon fiber arrangement layer and protects and stabilizes the carbon fibers during subsequent processing and handling. The pre-consolidated material layer is positioned at an angle to the carbon fiber arrangement layer. Multiple pre-consolidated material layers can be stacked above and below the carbon fiber arrangement, each of which can be positioned at various angles to the carbon fiber arrangement. Preferably, the angle is approximately 90 degrees, but other angles between 0 and ±90 degrees will suffice. The material layers can be polyester, polypropylene, polyethylene, nylon, aramid or carbon staple fibers.

The composite structure, including the layer of randomly arranged carbon fibers and the layers of pre-consolidated materials, is coated with a binder. The binder stabilizes the carbon fiber layer and the pre-consolidated layers. The binder can be applied to the composite structure in a number of ways, including but not limited to spraying the binder onto the composite structure or submersing the composite structure in a vessel containing a binder dispersion. Next, the composite structure is placed on a forming surface. Depending upon the shape of the preform part, the forming surface can be either a curved or planar surface. The forming surface can be integrated into a conventional mold or remain a distinct structure.

Pressure is applied to the composite structure to shape or form the structure into a desired preform shape. The desired preform shape is a near-net shape, or similar to the finished part shape. The application of pressure improves the structural performance characteristics of the preform part. Pressure can be

applied in a number of ways, including but not limited to using a vacuum bag. Alternatively, the forming surface could be integrated into a lower portion of a mold. A top portion of the mold can be positioned in close proximity to the lower portion such that the top portion exerts pressure on the composite structure to form the arrangement into the preform shape.

Heat is then applied to the composite to set the binder. While heat is applied, the composite structure remains in the desired preform shape. Once the binder has set, the composite structure has solidified and become stable; however, the structure is still pliable. Unlike a cured resin, a set binder permits the structure to remain pliable. As a result of the solidification, the resulting preform part is no longer structurally unstable and difficult to handle.

Similar to the method discussed above, heat can be applied in a number of ways to set the binder the composite, including but not limited to applying an electric current to the carbon fibers to resistively heat the composite structure. Alternatively, an electric current could be applied to a layer of conductive fibers in the forming surface to resistively heat the forming surface. By applying an electric current to the carbon fibers and to a layer of conductive fibers in the forming surface, the structure and the forming surface could be resistively heated. In yet another manner of heating the composite structure, an electric current could be applied to a layer of conductive fibers in the upper and lower mold portions to resistively heat the forming surface. In addition to applying an electric current to the upper and lower mold portions, an electric current could be applied directly to the carbon fibers in the structure. Alternatively, other conventional methods could be used to heat the carbon fiber arrangement, including ovens, autoclaves, ultraviolet light, or ambient temperatures.

Once a sufficient quantity of heat has been applied to set the binder, the resulting preform part is allowed to cool and is then removed from the forming surface. The preform part is then ready to be used in forming a finished part.

In another preferred embodiment, a single layer or multiple layers of randomly arranged carbon fibers or batt are manually stacked with a single layer

or multiple layers of pre-consolidated materials to form a composite structure. Preferably, a single layer of randomly arranged carbon fibers is surrounded by a layer of pre-consolidated material both above and below the randomly arranged carbon fiber layer. Each of the pre-consolidated layers can be positioned at various angles to the carbon fiber arrangement. Preferably, the angle is approximately 90 degrees, but other angles between 0 and ±90 degrees will suffice. As a result of this arrangement, the composite structure has structural components in the x-axis, the y-axis, and the z-axis.

Next, the composited structure is placed on a forming surface. Depending upon the shape of the preform part, the forming surface can be either a curved or planar surface. The forming surface can be integrated into a conventional mold or remain a distinct structure.

Pressure is applied to the composite structure to shape or form the structure into a desired preform shape. Pressure can be applied in a number of ways, including but not limited to using a vacuum bag. Alternatively, the forming surface could be integrated into a lower portion of a mold. A top portion of the mold can be positioned in close proximity to the lower portion such that the top portion exerts pressure on the composite structure to form the arrangement into the preform shape.

A binder is infused or injected into the composite structure while the structure remains under vacuum. The binder stabilizes the carbon fiber layer and the pre-consolidated layers. The binder can be infused or injected in a number of ways, including but not limited to using an injection port.

Heat is then applied to the composite to set the binder. While heat is applied, the composite structure remains in the desired preform shape. Once the binder has set, the composite structure has solidified and become stable; however, the structure is still pliable. As a result of the solidification, the resulting preform part is no longer unstable and difficult to handle.

The heat can be applied as previously set forth. Again, once a sufficient quantity of heat has been applied to set the binder, the resulting preform part is

allowed to cool and is then removed from the forming surface. The preform part is then ready to be used in forming a finished part.

While specific embodiments have been illustrated and described, numerous modifications are possible without departing from the spirit of the invention, and the scope of protection is only limited by the scope of the accompanying claims.

CLAIMS

We claim:

1. A method of forming a composite, comprising the steps of:

providing a layer of carbon fiber having a plurality of carbon fiber filaments;

providing a first and second layer of non-woven fibers;

assembling the first non-woven fiber layer above the carbon fiber layer and the second non-woven fiber layer below the carbon fiber layer; and,

consolidating the first and second non-woven fiber layers and the carbon fiber layer by needle-punching the layers with a plurality of down-stroke needles having a non-aggressive barb such that the filaments are pushed aside during the consolidating step.

2. The method of claim 1 wherein the carbon fibers are pan fibers.

3. The method of claim 1 wherein the carbon fibers are pitch fibers.

4. The method of claim 1 wherein the carbon fibers are one of continuous and discontinuous filaments

5. The method of claim 1 wherein the first and second non-woven fiber layers are polyester staple.

6. The method of claim 1 wherein the first and second non-woven fiber layers are polypropylene staple.

7. The method of claim 1 wherein the first and second non-woven fiber layers are nylon staple.

8. The method of claim 1 wherein the first and second non-woven fiber layers are aramid staple.

9. The method of claim 1 wherein the first and second non-woven fiber layers are fiberglass staple.

10. The method of claim1 wherein the first and second non-woven fiber layers have a fiber orientation defined on-line at a batt condenser by carding

and double-lapping the first and second non-woven fiber layers with a second carbon fiber layer before the consolidation step.

11. The method of claim1 wherein the first and second non-woven fiber layers have a fiber orientation defined off-line at a batt condenser before the consolidation step.

12. The method of claim 1 wherein the frequency of the needle-punching is in the range between 450 to 1000 penetrations per square inch.

13. The method of clam 1 further including the step of adjusting the pressure of the needle-punching such that carbon fibers and the non-woven fibers are placed into intimate contact to ensure an electrically conductive path through the composite.

14. The method of clam 1 further including the step of:

placing a flexible membrane over the composite;

drawing a vacuum between the membrane and the composite; and,

infusing a heat-curable resin into the composite.

15. A method of forming a composite, comprising the steps of:

providing a layer of carbon fiber having a plurality of carbon fibers filaments;

providing a first and second layer of non-woven fibers;

assembling the first non-woven fiber layer above the carbon fiber layer and the

second non-woven fiber layer below the carbon fiber layer; and,

consolidating the first and second non-woven fiber layers and the carbon fiber layer

by stitch-bonding the layers with a plurality of needles threaded with a continuos filament.

16. A method of forming a preform part, comprising the steps of:

coating an arrangement of carbon fibers with a binder;

placing the carbon fiber arrangement on a forming surface;

applying pressure to the carbon fiber arrangement; and,

applying heat to the carbon fiber arrangement to set the binder.

17. The method of claim 16, wherein the applying pressure step comprises using a vacuum bag.

18. The method of claim 16, wherein the applying heat step comprises applying an electric current to the carbon fibers to resistively heat the carbon fiber arrangement.

19. The method of claim 16, wherein the applying heat step comprises applying an electric current to a layer of conductive fibers in the forming surface to resistively heat the forming surface.

20. The method of claim 16, wherein the applying heat step comprises applying an electric current to the carbon fiber arrangement and to a layer of conductive fibers in the forming surface to resistively heat the arrangement and the forming surface.

21. The method of claim 16, including the additional step of introducing a curable resin into the preform part and using the preform part in a molding process to form a finished part.

22. The method of claim 16, wherein the arrangement of carbon fibers is randomly structured.

23. The method of claim 16, wherein the arrangement of carbon fibers is randomly structured in the machine direction.

24. The method of claim 16, wherein the binder is liquid adhesive.

25. The method of claim 16, wherein the binder is dry adhesive.

26. A method of forming a preform part, comprising the steps of:

coating an arrangement of carbon fibers with a binder;

placing the carbon fiber arrangement on a forming surface of a lower mold portion;

applying pressure to the carbon fiber arrangement with an upper mold portion; and,

applying heat to the carbon fiber arrangement to set the binder.

27. The method of claim 26, wherein the applying heat step comprises applying an electric current to a layer of conductive fibers in the upper and lower mold portions to resistively heat the upper and lower mold portions.

28. The method of claim 26, wherein the applying heat step comprises applying an electric current to a layer of conductive fibers in the upper and lower mold portions and to the carbon fiber arrangement to resistively heat the carbon fiber arrangement and the upper and lower mold portions.

29. A method of forming a preform part, comprising the steps of:

coating a random arrangement of carbon fibers with a binder;

placing the carbon fiber arrangement on a forming surface;

applying pressure to the carbon fiber arrangement to form the carbon fiber arrangement in a desired preform shape; and,

applying heat to the carbon fiber arrangement to set the binder while maintaining the desired preform shape.

30. A method of forming a preform part, comprising the steps of:

arranging a plurality of layers of carbon fibers and a plurality of layers of pre-consolidated materials to form a composite structure;

applying a binder to the composite structure such that the binder coats the carbon fiber layers and the pre-consolidated layers;

placing the composite structure on a forming surface;

applying pressure to the composite structure; and,

applying heat to the composite structure to set the binder.

31. The method of claim 30, wherein the applying pressure step comprises using a vacuum bag.

32. The method of claim 30, wherein the applying heat step comprises applying an electric current to the carbon fiber layers to resistively heat the carbon fiber layers.

33. The method of claim 30, wherein the applying heat step comprises applying an electric current to a layer of conductive fibers in the forming surface to resistively heat the forming surface.

34. The method of claim 30, wherein the applying heat step comprises applying an electric current to the carbon fiber layers and a layer of conductive fibers in the forming surface to resistively heat the carbon fiber layers and the forming surface.

35. The method of claim 30, including the additional step of introducing a curable resin into the preform part and using the preform part in a molding process to form a finished part.

36. The method of claim 30, wherein the binder is liquid adhesive.

37. The method of claim 30, wherein the binder is dry adhesive.

38. A method of forming a preform part, comprising the steps of:

arranging a plurality of layers of carbon fibers and a plurality of layers of pre-consolidated materials to form a composite structure;

applying a binder to the composite structure such that the binder coats the carbon fiber layers and the pre-consolidated layers;

placing the composite structure on a forming surface of a lower mold portion;

applying pressure to the composite structure with an upper mold portion; and,

applying heat to the carbon fibers layers to set the binder.

39. A method of forming a preform part, comprising the steps of:

arranging a plurality of layers of carbon fibers and a plurality of layers of pre-consolidated materials to form a composite structure;

applying a binder to the composite structure such that the binder coats the carbon fiber layers and the pre-consolidated layers;

placing the composite structure on a forming surface;

applying pressure to the composite structure to form the composite structure in a

desired preform shape; and,

applying heat to the carbon fiber layers to set the binder while maintaining the desired preform shape.

40. A method of forming a preform part, comprising the steps of:

arranging a plurality of layers of carbon fibers and a plurality of layers of pre-consolidated materials to form a composite structure;

placing the composite structure on a forming surface;

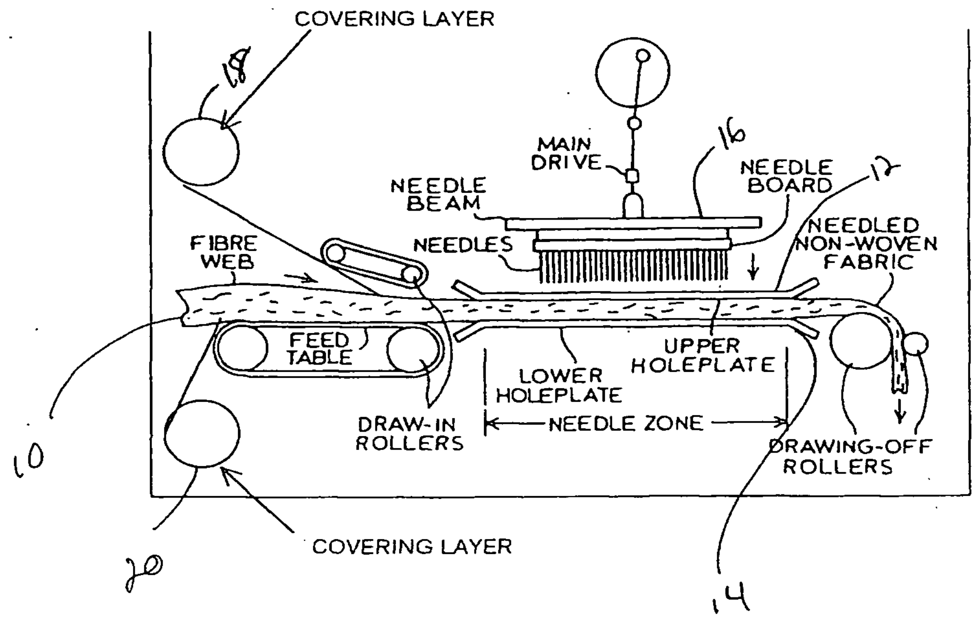
applying pressure to the composite structure;

infusing a binder into the composite structure such that the binder coats the carbon fiber layers and the pre-consolidated layers; and,

applying heat to the composite structure to set the binder.

41. The method of claim 16, wherein the binder is in the form of a low melting temperature thermoplastic yarn or filament combined or interlaced with the carbon fibers

FIG. 1


COVERING LAYER
18
MAIN DRIVE
16
NEEDLE BEAM
NEEDLE BOARD
12
NEEDLES
FIBRE WEB
NEEDLED NON-WOVEN FABRIC
FEED TABLE
UPPER HOLEPLATE
LOWER HOLEPLATE
DRAW-IN ROLLERS
NEEDLE ZONE
DRAWING-OFF ROLLERS
10
COVERING LAYER
20
14

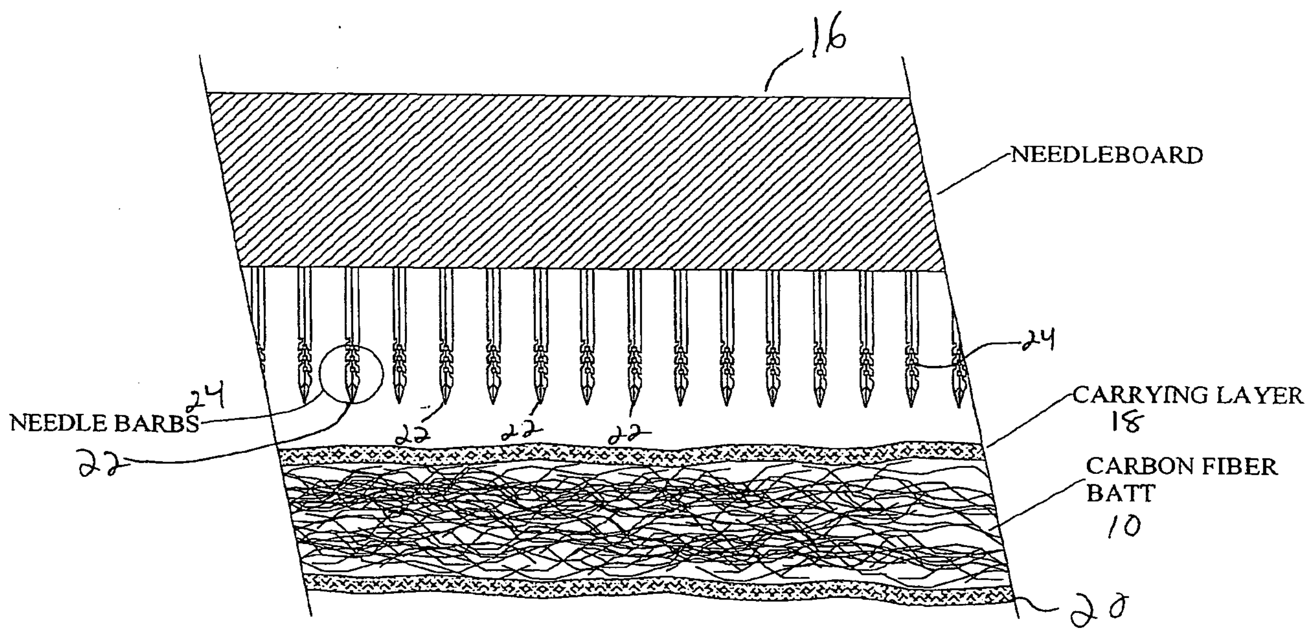

16
NEEDLEBOARD
24
24
NEEDLE BARBS
22
22
22
22
CARRYING LAYER
18
CARBON FIBER
BATT
10
20

Fig. 2

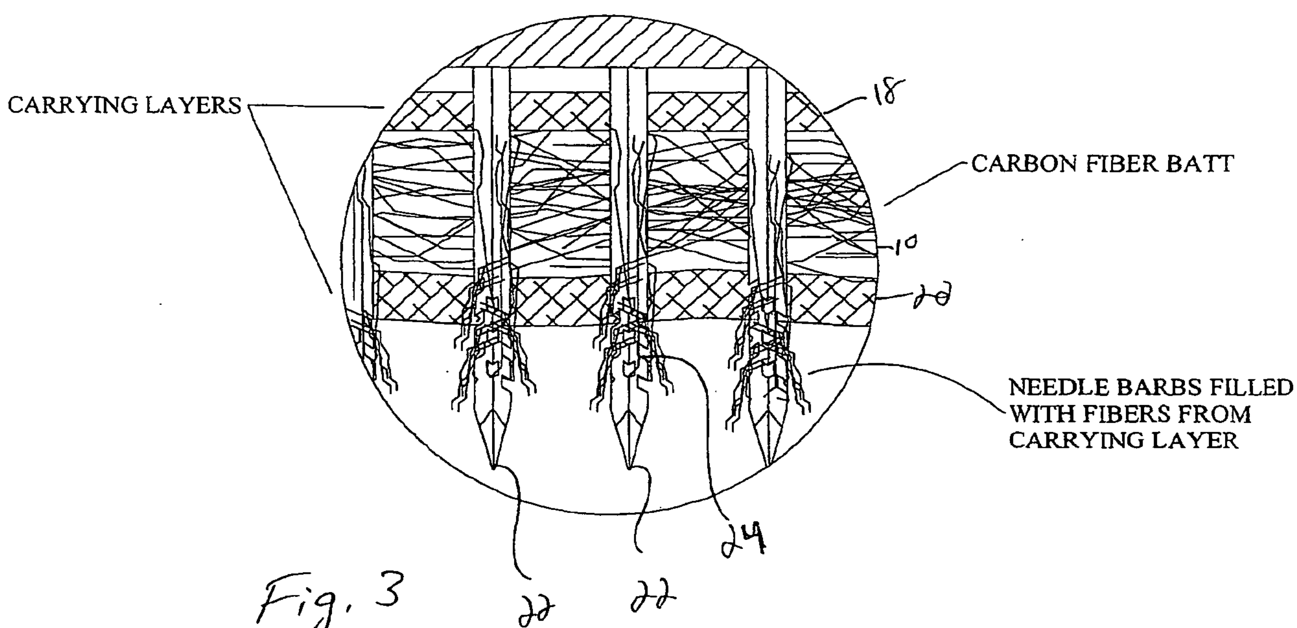

CARRYING LAYERS
18
CARBON FIBER BATT
10
20
NEEDLE BARBS FILLED WITH FIBERS FROM CARRYING LAYER
24
22
22

Fig. 3

FIG. 4

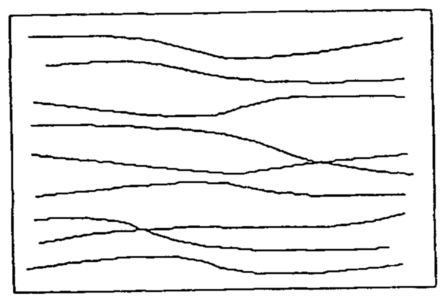


FIG 5

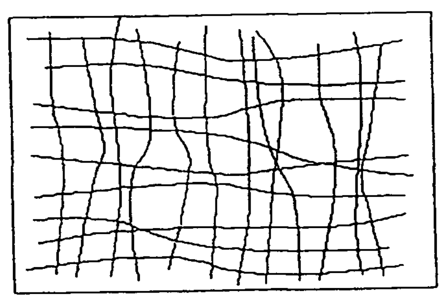


FIG 6